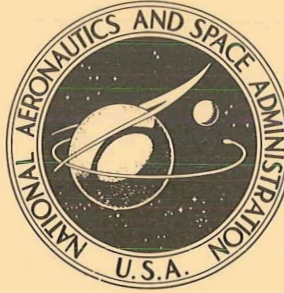


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# FILAMENTARY CRYSTAL GROWTH ASSOCIATED WITH HYPERVELOCITY MICROPARTICLE IMPACT CRATERS

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16. Abstract  A filamentary crystal growth is associated with hypervelocity microparticle impacts upon copper foil. Consideration of facts concerning the projectile impacts and observations of their characteristics lead to a conclusion that they are copper whiskers formed by the condensation of the target material vaporized by the impact.					
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# FILAMENTARY CRYSTAL GROWTH ASSOCIATED WITH HYPERVELOCITY MICROPARTICLE IMPACT CRATERS

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## INTRODUCTION

An interesting filamentary crystalline growth is observed in the immediate area of hypervelocity microparticle impact sites upon thin copper foil. Carbonyl iron spheres ranging in diameter from  $0.05\mu$  to  $5\mu$  were accelerated in an electrostatic accelerator to velocities of 1.5 to 50 km/sec and impinged upon rolled copper foil of  $3\mu$  thickness. The impacts occurred while the thin film was at room temperature and at a pressure of  $5 \times 10^{-6}$  torr.

Portions of the exit side of the foil were photographed at magnifications of 1450X, 5400X, and 14,000X with a Cambridge scanning electron microscope and are shown in Figures 1, 2, and 3, respectively. Approximately 27 percent of the projectiles penetrated the foil as shown. Unfortunately, neither particle velocity nor particle size can be correlated with any specific impact sites shown. However, from past studies of craters produced in thin films by hypervelocity microparticles, it is safe to assume that the successful penetrations and the larger impact areas were caused by the larger and, consequently, slower particles in the preceding range of velocities and dimensions.

## OBSERVATIONS

Several interesting features concerning the filamentary crystalline growth are revealed by the photographs of the exit side of the foil. (The filamentary phenomenon does not appear on the impact side of the foil.)

(1) The filaments exhibit great strength. The average diameter of the stem between the nodules is around  $0.2\mu$ , while the overall filamentary length often exceeds  $12\mu$ . This structure survived repeated exposures to vacuum and atmospheric pressure and to ambulatory transportation between buildings. There is a noticeable absence of broken or separated filaments lying on the surface.

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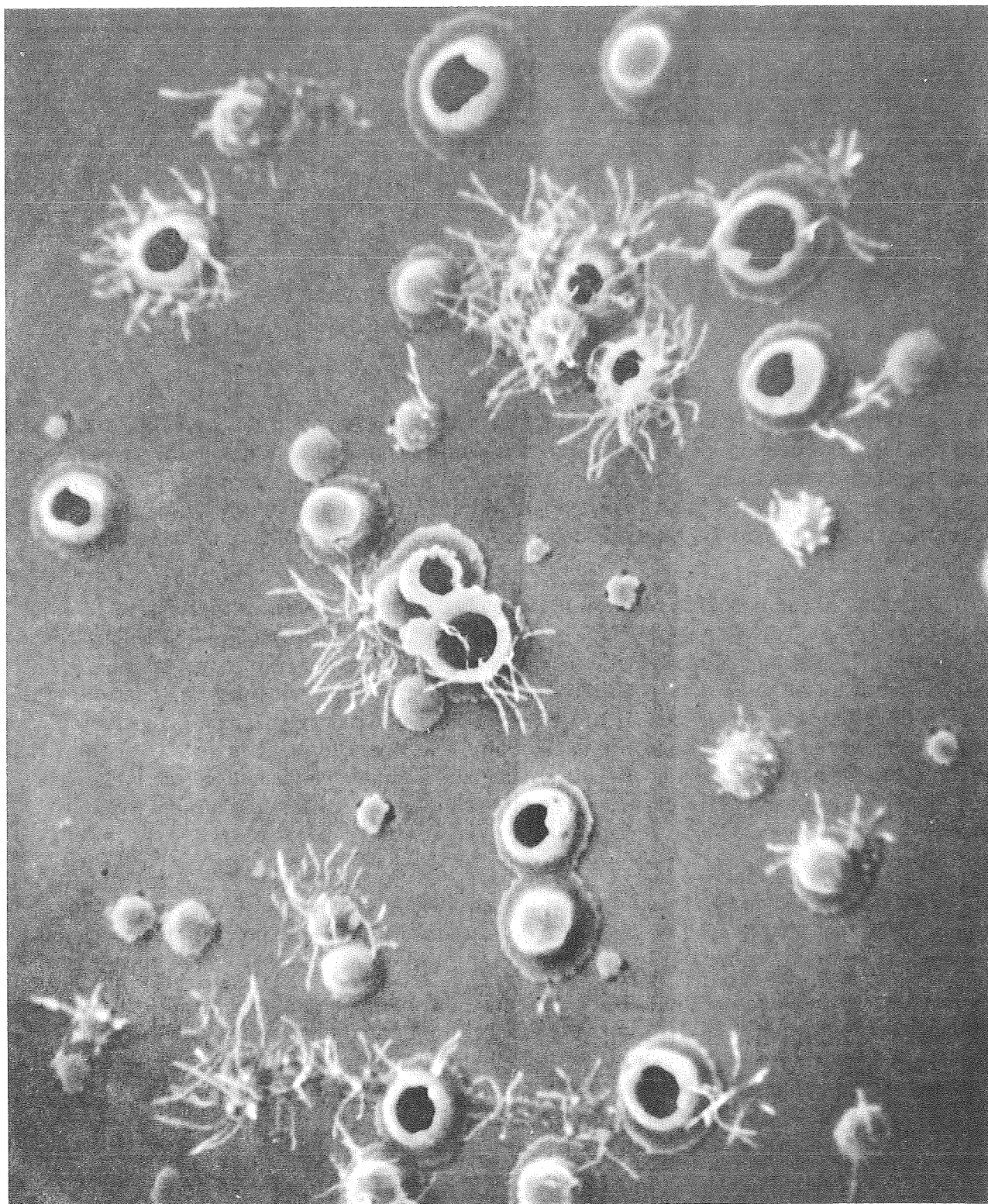


Figure 1—Exit side of copper foil (1450 $\times$ ).



Figure 2—Impact site cluster shown in upper right of Figure 1 (5400x).

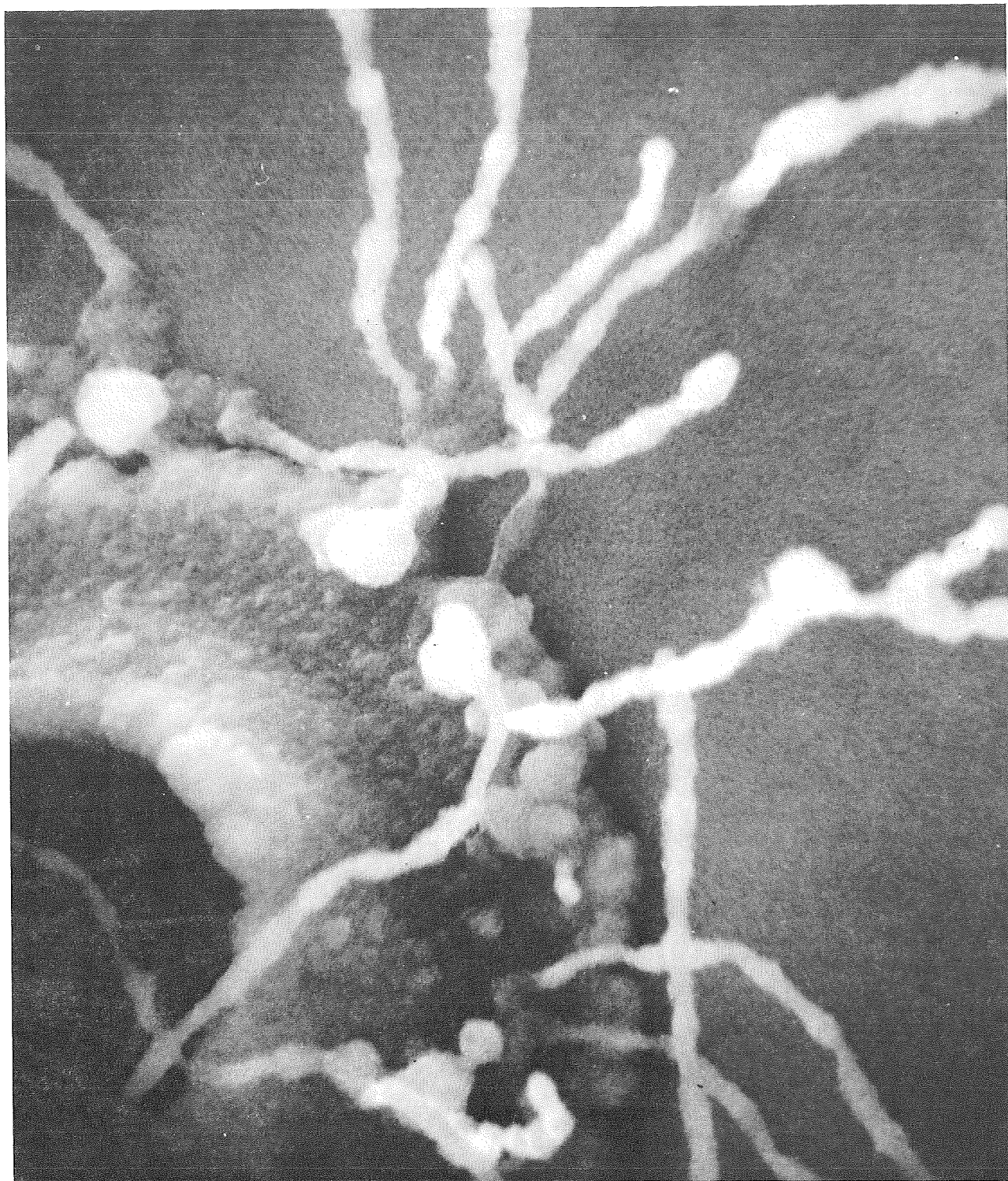


Figure 3—Portion of the same impact site cluster shown in Figure 2 (14,000 $\times$ ).

(2) The filaments appear on several of the impact areas that do not show penetration. This observation essentially rules out interaction between the iron in the projectile and the copper metal.

(3) Some of the filaments are branched, indicating a relatively slow growth or formation as opposed to violent formation by ejecta, high temperature spewing, or extrusion.

(4) The filaments have propagated all along the surface flaw line (at the bottom of Figure 1). This is a further suggestion that they are the result of growth rather than violent formation.

(5) The nodules in the filaments are similar to the structure surrounding the perforations (see Figure 3).

## CONCLUSIONS

The following preliminary conclusions are based on a study of the photographs shown and the considerations of physical phenomena normally associated with the hypervelocity microparticle impact.

(1) The strength exhibited by the filaments suggests single crystals of copper, or copper whiskers, formed by the condensation of copper vapor surrounding the exit side of the impact site. Studies by Brenner (Reference 1) have shown that the elastic limit and tensile strength of whiskers are "100 to 1000 times greater than that of the annealed bulk crystal." The extremely high pressure and temperature conditions prevalent during particle impact on the foil are highly favorable to the formation of copper vapor. Similarly, the low-pressure volume surrounding the foil and the impact site are highly favorable to the postimpact condensation of the copper vapor. Theoretical studies by Sodek (Reference 2) indicate that pressures as high as 12 Mb develop in  $0.017 \times 10^{-9}$  seconds in a volume of the target immediately below the impact site. Less than 1 nsec later, this high-pressure volume of copper erupts on the exit side of the foil into the ambient vacuum chamber pressure of  $5 \times 10^{-6}$  torr, and condensation occurs.

(2) The absence of whiskers on the impact side of the foil is probably due to the fact that the ultra-high-speed ejecta or secondary spray normally associated with the impact side of the hypervelocity particle impact site removed the copper vapor too quickly for localized condensation.

(3) The absence of whiskers on the exit side of some of the impacts is not readily explained, except to say that conditions for the formation of whiskers are probably quite critical and that these conditions did not necessarily prevail at all the impact sites.

Some consideration was given to an explanation that the whiskers were products of high-impact plastic deformation of individual copper crystals in the rolled foil. However, the branched filaments and the propagation of the whiskers along the flaw line tend to negate such an explanation.

The formation of the whiskers was an unexpected phenomenon that occurred during penetration experiments on thin films conducted by J. A. M. McDonnell at the Goddard Space Flight Center. Unfortunately, the electron-microscope photographs were late in arriving (they were not a necessary part of the penetrations experiment), and the foil sample was destroyed. Consequently, no analytical studies of the composition of the whiskers were made. To date, several repeated attempts at reproducing the phenomenon have failed. If future attempts to reproduce the whiskers are successful, composition will be determined, and better correlation made between projectile size and velocity and filamentary growth.

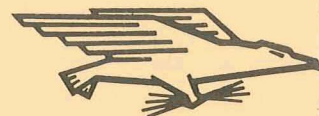
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National Aeronautics and Space Administration  
Greenbelt, Maryland, January 21, 1970  
811-12-02-81-51

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